

February 21, 1895.

The LORD KELVIN, D.C.L., LL.D., President, followed by Sir JOHN EVANS, K.C.B., D.C.L., LL.D., Vice-President and Treasurer, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

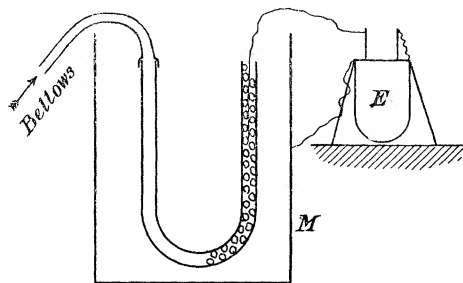
The following Papers were read :—

- I. "Electrification of Air and other Gases by bubbling through Water and other Liquids." By LORD KELVIN, P.R.S., MAGNUS MACLEAN, M.A., F.R.S.E., and ALEXANDER GALT, B.Sc., F.R.S.E. Received February 7, and February 15, 1895.

§ 1. At the meeting of the British Association in Oxford in August, 1894, a communication was given to section A, entitled "Preliminary Experiments to find if Subtraction of Water from Air Electrifies it." These experiments were performed during July of 1894, and were a continuation of experiments which were commenced in the Physical Laboratory of the University of Glasgow in December of 1868 with the same object, but which were then, for various reasons, discontinued before any decisive result had been obtained.

§ 2. A glass U-tube with vertical branches (fig. 1), each 18 inches long and about 1-inch bore, with the upper 8 inches of one of the branches carefully coated outside and inside with clean shellac varnish, was held fixed by an uninsulated support attached to the upper end of this branch. The other branch was filled with little fragments of pumice soaked in strong sulphuric acid or in water, and a fine

FIG. 1.

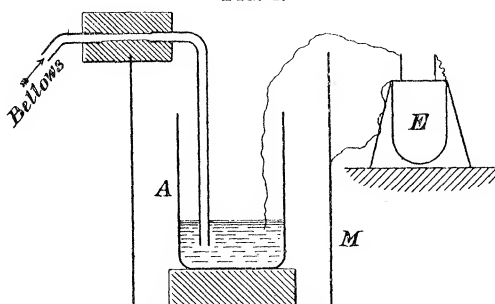


platinum wire, with one end touching the pumice, connected it to the insulated electrode of a quadrant electrometer. A metal can, M, large enough to surround both branches of the U-tube without touching either, was placed so as to guard the tube from electric influences of surrounding bodies, the most disturbing of which is liable to be the woollen cloth sleeves of the experimenters or observers moving in the neighbourhood. This metal can was kept in metallic connection with the outside metal case of the quadrant electrometer. The length of the exposed platinum wire between the U-tube and the electrometer was so short that it did not need a metal screen to guard it against irregular influences. An india-rubber tube from an ordinary blow-pipe bellows was connected to the uninsulated end of the U-tube. Air was blown through it steadily for nearly an hour. With the pumice soaked in strong sulphuric acid in the other branch, the electrometer reading rose in the course of three-quarters of an hour to about 9 volts positive. *When the pumice was moistened with water, instead of sulphuric acid, no such effect was observed.* The result of the first experiment proves decisively that the passage of the air through the U-tube gave positive electricity to the sulphuric acid, and therefore sent away the dried air with negative electricity. A corresponding experiment with fragments of pure chloride of calcium instead of pumice in sulphuric acid, gave a similar result. In repetition of the experiments, however, it was noticed that the strong positive electrification of the U-tube seemed to commence somewhat suddenly when a gurgling sound—due to the bubbling of air through free liquid, whether sulphuric acid or chloride of calcium solution in the bend of the U-tube—began to be heard. It has since been ascertained that it was because no liquid accumulated in the bottom of the U-tube that no electric effect was found when the pumice was moistened with pure water.

§ 3. Arrangements were made to prevent any bubbling of the air through liquid, by using a straight tube instead of a U-tube. In a large number of experiments with pumice, moistened with pure sulphuric acid, in the straight tube, and air blown through for about half an hour, no definite electrification was obtained. In this straight tube, as formerly with the U-tube, pumice moistened with pure water gave no electrification. Chloride of calcium in lumps, not specially dried, gave no effect in the straight tube; but if previously heated to 180° or 200° and put into the straight tube when still hot, it gave an enormous positive electrification immediately on the commencement of blowing. Strong positive electrification was obtained a second time, by discharging the electrometer to zero, re-insulating, and re-commencing the blowing. But after discharging a second time, re-insulating, and re-commencing the blowing, no further electrification was found.

§ 4. In continuation of these experiments, on the 25th of September the arrangement represented in fig. 2 was set up. An outer

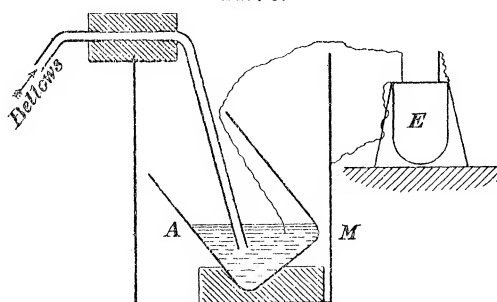
FIG. 2.



metallic guard-vessel, *M*, was kept connected by a wire to the case and to one pair of quadrants of a quadrant electrometer, *E*. Water in an inner glass or metal jar, *A*, was connected by a platinum wire to the other pair of quadrants of the electrometer. To have this inner jar well insulated, it was supported on a block of paraffin; and the upper end of a glass tube dipping into the water was fitted into one end of a tube of paraffin, to the other end of which was fitted a tube for ingress of air, from bellows, as shown in the figure. The insulation of this arrangement was found to be good. When air was blown through the water it was found that the jar containing the water became positively electrified.

§ 5. To prevent splashing of water out of the jar, a paper cover was put on its mouth, or the jar was tilted, as shown in fig. 3,

FIG. 3.



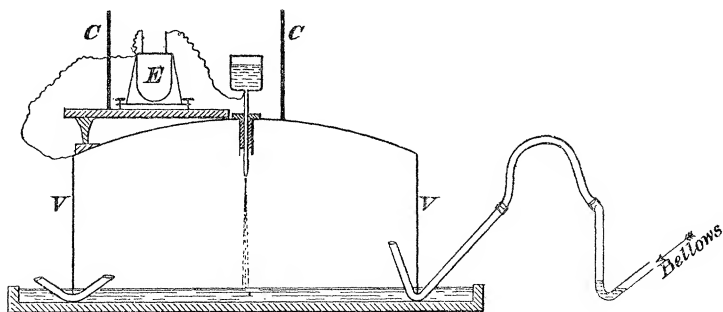
so that the bubbles broke against the inside of the jar. In three experiments thus made, the same electrification was still found, amounting to about 6 volts positive in a quarter of an hour.

§ 6. As the jar was in every experiment positively electrified, the

air, if unelectrified* when entering it, must have been negatively electrified when leaving it.

§ 7. To test if the air was negatively electrified after bubbling, on the 11th of October the apparatus† shown in fig. 4 was set up. The

FIG. 4.



apparatus consists of a large sheet iron vat, VV, 123 cm. in diameter and 70 cm. in height, inverted on a large wooden tray lined with lead, and supported by three blocks of wood. By filling the tray with water, the air is confined in the vat.

CC is a metal screen kept metallically connected with the case of the electrometer, and with the vat. It surrounds both the electrometer and the water-dropper, to prevent any external varying electrifications from vitiating the proper results of our experiments.

This screening of the electrometer is absolutely necessary when it is used with high sensibility (70 scale divisions per volt in our experiments) in a laboratory or other place where various other electric experiments may simultaneously be going on. Four years ago the electrometer, the vat, and the water-dropper, were set up on the class-room table *without a metal screen*. When the deflection indicated about 4 volts negative (see § 8), the negative lead of Lord Kelvin's house electric-light circuit, which passes through the class-room, was joined to earth. This changed the deflection of the electrometer suddenly by 1 volt[‡] in the positive direction. When the positive lead was "earthed," the deflection was changed suddenly by 6 volts in the negative direction. Putting on sixteen 8 c.p. electric lamps, eight on each side of the class-room, changed the deflection by two-thirds of a volt in the negative direction.

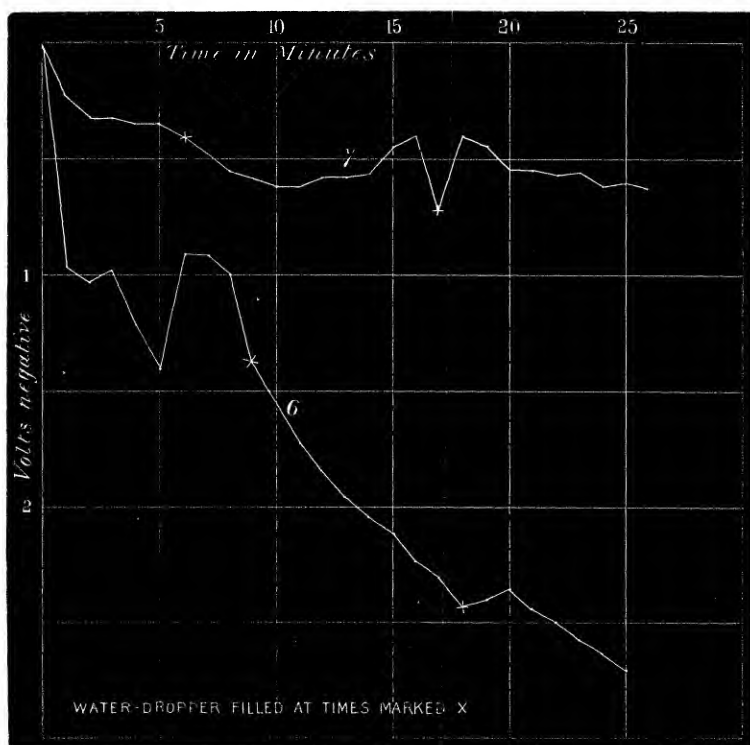
* Air was similarly blown from bellows into the vat (see § 7) without any bubbling, and no electrification was observed.

† The vat, the water-dropper, and the electrometer are the same as in the apparatus described in the 'Proceedings of the Royal Society,' vol. 56, year 1894, "Electrification of Air," by Lord Kelvin and Magnus Maclean.

§ 8. In experimenting with the same apparatus* in 1890 it was found that the water jet gave negative electricity to the ordinary air of the laboratory enclosed in the vat. The present experiments fully confirm this result, showing a gradual negative electrification of the enclosed mass of air rising to about 5 volts in an hour, once every day for the first few days. For twenty-eight days after the vat was set up in October, 1894, fifteen observations of an hour each were taken, to find the effect of the water-dropper, with no other disturbing influence on the unchanged volume of air inside the vat. These experiments verify the conclusion ('Phil. Mag.,' August, 1890) that the more the air inside the vat became free of dust, the less became the rate at which the air was negatively electrified by the water-dropper.

§ 9. On the 15th October last the vat was lifted from the tray to remove some obstruction in the nozzle of the water-dropper, which was not then flowing freely. Curve (6) was obtained that afternoon.

CURVES 6 AND 7.

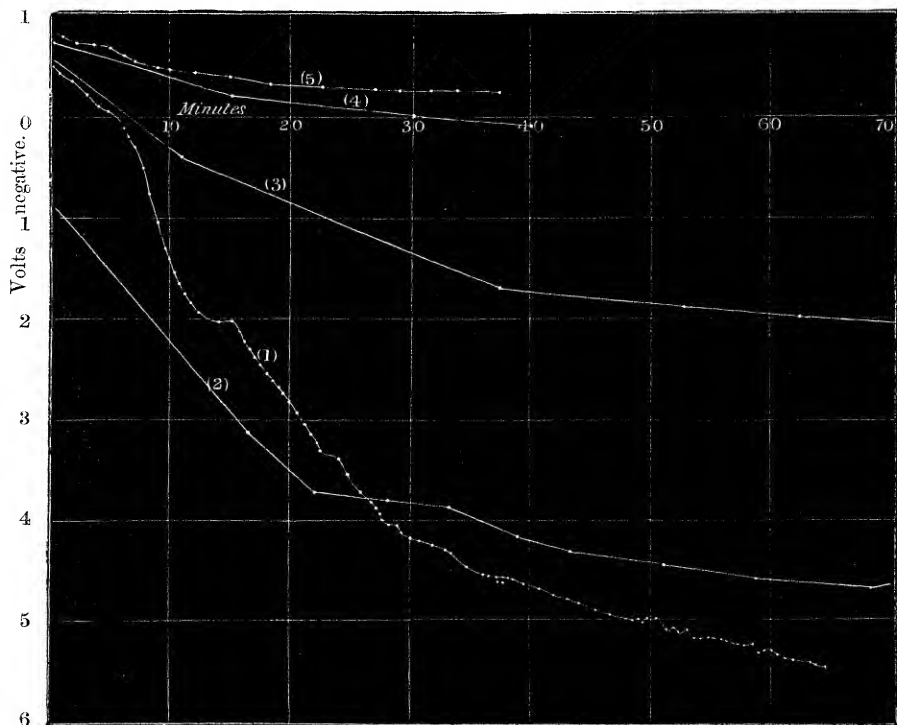


* 'Phil. Mag.,' August, 1890, "Electrification of Air by a Water Jet," by Maclean and Goto.

The air in the vat was the ordinary air of the laboratory, and the curve shows the effect of the water-dropper alone in electrifying the air negatively. For the next two days the water-dropper was kept running continuously for about eight hours each day, to wash the dust out of the air, and on the 18th of October curve (7) was obtained. It shows a much less rate of negative electrification than curve (6). In the experiments of summer 1890 an aspirator was used to draw the air from the vat, and a tube full of cotton-wool was used to filter the air drawn into the vat.

Curves (1) to (5) are reproduced from the 'Philosophical Magazine,' and they show that the more the air becomes free from dust the less is the rate at which the water-dropper electrifies. Thus curve (1) was obtained from the ordinary air of the laboratory, in the vat, and curve (2) after the aspirator was working for some time. In this curve the water-dropper itself was running for some time before the first observation was taken. The other curves were obtained after further continuous working of the aspirator.

CURVES 1 TO 5.

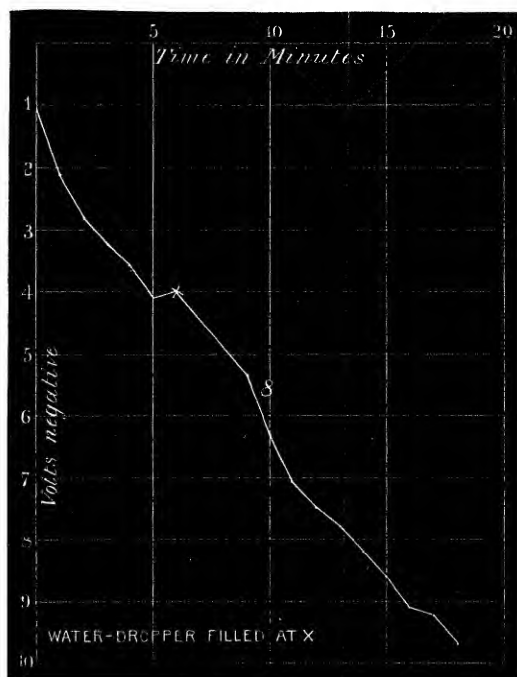


After curve (4) was obtained the aspirator was worked continuously for twenty-five hours, and then curve (5) was obtained.

§ 10. At the end of twenty-three days of October and November 1894 (§§ 8, 9 above), when the air inside the vat must have been fairly free from dust, and when the water-dropper of itself was giving little negative electrification, we bubbled air into it by a forked tube, one end of which was connected to a bellows, and three other open ends were below the water inside the vat. In five experiments thus made—two on November 7, two on November 8, and one on December 17—an average negative electrification of 5 volts in twelve minutes was obtained.

§ 11. We now arranged a U-tube with pure water in it (fig. 4) outside the vat. Air from the bellows bubbled through the water in this U, and was carried thence by a block-tin pipe into the vat without any further bubbling. Observations by the quadrant electrometer, while the water-dropper was running and the bellows worked, gave us measurements of the varying state of the electrification of the air in the vat. The average of fifteen experiments gave a negative electrification of the air in the vat of $8\frac{1}{2}$ volts in 25

CURVE 8.



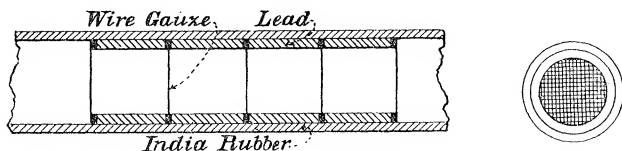
minutes. The rate at which the air was blown in in these experiments was such as to displace the entire volume of air in the vat in half an hour.

§ 12. Curve (8) shows the rate of electrification of air, in one of the fifteen experiments, when thus bubbled through the water in the U-tube and then admitted into the vat.

§ 13. Two U-tubes, in series, with water in each, did not seem to give a perceptibly cumulative effect.

§ 14. The effect of one or more wire gauze strainers between the U-tube and the vat, or between the U-tube and the bellows, was next tested. The gauzes were placed between short lengths of lead tube, which were held together by a rubber tube slipped over them. The arrangement is shown by longitudinal and cross sections in fig. 5.

FIG. 5.



Twelve wire gauzes, with or without cotton-wool between them, placed between the bellows and the U-tube, did not prevent the subsequent electrification by bubbling of the air thus filtered. But when placed between the U-tube and the vat they almost entirely diselectrified the air, even without the cotton-wool, and still more decidedly when cotton-wool was loosely packed between the wire gauzes. A single wire-gauze strainer produced but little of dis-electrifying effect.

§ 15. The interpretation of these experiments is complicated, and the time required for each is lengthened, on account of the large mass of air in the vat to start with, whether uncharged or retaining electricity from previous experiments, and also on account of the effect of the water-dropper itself. Hence, in our later experiments, we fell back on the arrangement shown in fig. 2, by which we test the electrification of the liquid, and not directly that of the gas blown through it.

§ 16. In our first experiments with this apparatus the amount of the electrification did not seem much affected when a paper cover was put on the jar, or when we tilted the jar as shown in fig. 3. We now made a large number of tests with different covers and screens (chiefly of sheet copper or sheet zinc, or brass wire gauze) at different heights above the liquids, and we concluded that, if the screens are not within a centimetre and a half of the liquid surface, they do not directly affect the magnitude of the electrification obtained. In nearly all of the subsequent experiments a horizontal circular screen

of thin sheet copper, leaving an air space of about 3 mm. all round between its edge and the inner surface of the jar, about 3 cm. above the liquid surface, was used to prevent spherules of the liquid from being tossed out of the jar by the bubbling.

§ 17. In the following short summary of our results the duration of each experiment was 10 minutes. The effect of blowing air through water and other liquids is summarised in §§ 18 to 27, and of blowing other gases than air through water in §§ 28 to 31.

§ 18. The jar contained 200 c.c. of the Glasgow town-supply water (from Loch Katrine). A mean of seventeen experiments showed an electrification of the jar to 4 volts positive when air was blown through it for 10 minutes.

§ 19. A solution of zinc sulphate of different strengths was now used instead of the pure water. Three experiments, with 150 c.c. of water containing one drop of a saturated solution of the zinc sulphate, gave half the positive electrification that would, under similar circumstances, have been obtained from water only. With five drops no definite electrification was obtained. With greater proportions of the zinc sulphate solution up to saturation (twenty-four experiments altogether) the electrification was on the average slightly negative.

§ 20. Twelve experiments were then made to test the effect of adding a solution of ammonia to the water. One drop reduced the electrification to one-half; two drops brought it down to one-quarter. With larger proportions of ammonia than this, up to a saturated solution, we found a very slight positive electrification, never amounting to more than a small fraction of a volt, and therefore negligible in the circumstances.

§ 21. Seven experiments with sulphuric acid of different strengths all showed small *positive* electrification, the amount gradually decreasing from $\frac{1}{4}$ volt, in 10 minutes, with 0.5 per cent. acid in water to $\frac{1}{16}$ volt, in the same time, with acid of full strength.

Seven experiments with hydrochloric acid solution of different strengths all showed a small *negative* electrification, the amount gradually increasing from $\frac{1}{2}$ volt, in 10 minutes, with $\frac{1}{3}$ per cent. acid solution in water to $1\frac{1}{4}$ volts, in the same time, with acid solution of full strength.

Nine experiments with calcium chloride solution were made. A saturated solution and a solution diluted to 75 per cent. of full strength gave no result; but solutions of gradually diminished strength, from 50 per cent. down to $\frac{1}{10}$ per cent., showed a negative electrification from fully $\frac{1}{2}$ volt, in 10 minutes, down to $\frac{1}{8}$ volt.

Additions of very small quantities of washing soda to water greatly reduce the positive electrification obtained.

Loch Katrine water, supersaturated with carbonic acid, and placed

§ 29. The blowing of oxygen from a cylinder, obtained from the Oxygen Company, through water, gave as a mean of four experiments, a positive electrification to the water of half a volt in 10 minutes. When continued for 55 minutes, it gave the very decided result of 5 volts positive.

§ 30. Hydrogen prepared from zinc and dilute sulphuric acid was passed into a large metal gas-holder; and was passed on from this to bubble through the water in the insulated jar. In two experiments this was done immediately after the preparation of the hydrogen; in another it was done after the hydrogen had remained 18 hours in the gas-holder. In each of the three experiments the water was electrified to 2 volts positive in 10 minutes.

When the hydrogen was allowed to pass direct through a tube from the Wolffe's bottle where it was generated, to bubble in the insulated jar, the magnitude of the effect obtained was very much larger. In one case a mixture of muriatic acid and sulphuric acid and water was used, and the reading went off the scale positive in 30 seconds (more than 10 volts). In other two experiments, with dilute sulphuric acid and zinc in the Wolffe's bottle, the electrifications obtained were 6 volts positive in 7 minutes, and 7·3 volts positive in 13 minutes, in the last of which the hydrogen was allowed to bubble through caustic potash contained in a small bottle between the Wolffe's bottle and the insulated jar.

The hydrogen was next generated in the insulated jar itself, the tube for ingress of air used in the ordinary experiments being taken away. 200 c.c. of pure water, along with some granulated zinc, was put into the jar. Then some pure sulphuric acid was added, and electrometer readings were taken. In two experiments with no screen in the jar (§ 16) the reading went off the scale *negative* (1) in 2 minutes and (2) in 4 minutes (more than 9 volts in each case). In another experiment, in other respects the same, but with a copper screen 7 cm. above the surface of the liquid, the electrification showed 2 volts *negative* in 2 minutes, then came back to zero in 5 minutes, and in the next 6 minutes went 4 volts *positive*. The jar and pair of quadrants connected with it were then metallically connected with the outer case of the electrometer for a few seconds, and reinsulated; in 5 minutes the reading went up to 2 volts *positive*. A little more sulphuric acid was added to the jar, which was disinsulated for a short time and reinsulated; the reading went up to 7 volts *positive* in 4 minutes. The jar was again disinsulated for a few seconds and reinsulated; the reading went up in $4\frac{1}{2}$ minutes to $6\frac{1}{2}$ volts *positive*.

§ 31. Coal-gas, bubbled through water in the insulated jar, gave 1·4 volts positive in 10 minutes.

§ 32. In the ordinary experiment of bubbling air through a small

quantity of water in the bottom of the jar it was noticed that the electrification did not commence to be perceptible generally till about the end of the first minute; and that it went on augmenting perceptibly for a minute or more after the bubbling was stopped. The following experiment was therefore tried several times. One of us stood leaning over the jar, with the head about 10 ins. above it, and the mouth so partly closed that breathing was effected sideways; another blew the bellows; and another took the readings of the electrometer. After bubbling had been going on for some minutes, and the readings were rising gradually (4 volts per 10 minutes, as in § 18), blowing was stopped. As soon as the bubbling ceased, the first-mentioned observer, without moving his head or his body (see § 7, regarding the necessity to have the electrometer screened from outside influences) blew into the jar to displace the negatively electrified air in it. In every case the electrometer reading showed instantly a small rise in the positive direction.

In the carrying out of these experiments we have received much valuable help from Walter Stewart, M.A., and Patrick Hamilton, B.Sc.

§ 33. The very interesting experiments described by Lenard, in his paper on the Electricity of Waterfalls,* and by Professor J. J. Thomson, on the Electricity of Drops,† show phenomena depending, no doubt, on the properties of matter to which we must look for explanation of the electrical effects of bubbling described in our present communication, and of the electrification of air by drops of water falling through it, to which we have referred as having been found in previous experiments which were commenced in 1890 for the investigation of the passage of electrified air through tubes.‡

II. "Note on the Spectrum of Argon." By H. F. NEWALL. Communicated by LORD RAYLEIGH. Received February 14, 1895.

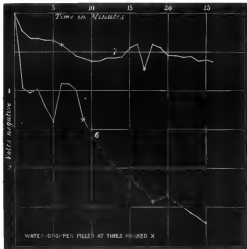
In the course of a spectroscopic investigation in which I have been for some time past engaged, a line spectrum, which so far as I was able to make out was unknown, has frequently presented itself upon my photographs. It appeared in May and June, 1894, under conditions which led me to call it, for the sake of convenience, "the low-pressure spectrum." After their announcement at the Oxford meeting of the British Association, it seemed for many reasons

* 'Wiedemann's Annalen,' 1892, vol. 46, pp. 584—636.

† 'Phil. Mag.,' April, 1894, vol. 37, pp. 341—358.

‡ "Electrification of Air by a Water Jet." By Magnus Maclean and Makita Goto, 'Phil. Mag.,' August, 1890, vol. 30, pp. 148—152.

CURVES 6 AND 7.



" 'Phil Mag.,' August, 1890, "Electrification of Air by a Water Jet," by Maclean and Goto.

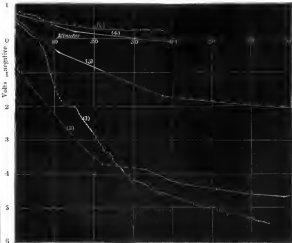
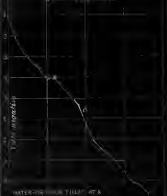


Figure 10. *Mytilus* sp.



WATER TEMPERATURE TILLER AT 10